Subjective Assessment of In-Vehicle Auditory Warnings for Rail Grade Crossings

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ABSTRACT

Human factors research has played an important role in reducing the incidents of vehicle-train collisions at rail grade crossings over the past 30 years. With the growing popularity of in-vehicle infotainment systems and GPS devices, new opportunities arise to cost-efficiently and effectively alert drivers of railroad crossings and to promote safer driving habits. To best utilize this in-vehicle technology, 32 auditory warnings (16 verbal, 7 train-related auditory icons, and 9 generic earcons) were generated and presented to 31 participants after a brief low-fidelity driving simulation. Participants rated each sound on eight dimensions deemed important in previous auditory warning literature. Preliminary results and possible interpretations are discussed.

1. INTRODUCTION

The number of collisions occurring between trains and vehicles has been greatly reduced in recent decades, with an 80% decrease in collision rates between 1980 and 2013 [1]. However, despite extraordinary efforts to prevent accidents, there were still 2,097 collisions involving trains and motorists in the United States in 2013 according to statistics from the Federal Railroad Administration [1]. Driver misunderstanding of visual warnings and other human errors account for many of these collisions. Appropriate action at grade crossings requires the driver to first interpret the signage (i.e., there is a crossing ahead and there may be a train, and comply with traffic laws). Second, the driver must visually scan for the presence of a train. Third, the driver must decide upon the appropriate action (i.e., stop when there is a train, or continue if train is absent) [2]. The two types of grade crossings, passive and active, provide different cues to the driver.

1.1. Passive versus active crossings

Active crossings use a combination of signs, gates, flashing lights, and bells to warn drivers of an approaching train. Passive crossings use a crossbuck sign and pavement markings, which merely alert the driver to the presence of a crossing, but do not provide any information on the likelihood of an approaching train. Active devices provide the driver with information on the presence or absence of a train, and often provide physical barriers (such as a gate) when a train is present. Active devices provide more guidance on the appropriate actions to take when confronted with a railroad crossing. Passive crossings leave much of the responsibility to the driver, leading to different types of human error [2].

As of 2014, 36% of grade crossings in the U.S. were equipped with only passive warning devices. On a unit-of-traffic basis, active warnings with gates are 80 to 90% more effective than just a crossbuck or STOP sign (passive warnings) in alerting drivers of their duties / reducing collisions [3]. However, the cost of installing and maintaining active devices far exceeds that of passive devices. The high cost means that only crossings deemed as high priority are equipped with active warning devices. While it is not feasible to upgrade all passive crossings with active devices, efforts are being made by industry, government, and academia to reduce collisions as much as possible.

1.2. In-vehicle auditory warning systems

One possible avenue for reducing collisions and increasing compliant behavior with regards to rail grade crossings is the use of Intelligent Transportation Systems (ITS) and connected -vehicle technology. This technology can connect the car/driver to the rail infrastructure for a more intelligent, informative, and reliable warning system. Many newer vehicles come equipped with collision avoidance systems (CASs) designed to detect and warn the driver of hazards. These CASs support the feasibility of developing a system to detect and warn drivers of the presence of trains and rail crossings.

Since driving is already a visually intensive task, many CASs use alternative modalities to deliver warning messages. Research on the effectiveness of collision warnings has shown that these alternate modalities may be easier for the driver to understand, and thus, reducing the time it takes to make a corrective action [4]. Specifically, auditory cues have shown promise in providing simple and intuitive cues to direct driver attention to potential hazards [5]. There are many things to consider when choosing auditory stimuli for a collision avoidance system. For instance, the cue must convey an appropriate sense of urgency for the situation at hand. Too little or too much perceived urgency can negatively influence the way the driver reacts [4, 6]. The sound must be designed to be heard over sounds occurring in the driving environment, such as engine sounds, radio, or conversation [6, 7]. The sound should be meaningful to the driver, provide enough information to describe the referent, and allow the driver to respond appropriately [5-7].

2. AUDITORY DISPLAY DESIGN

An experiment of prospective auditory warnings was conducted using the PEBL (software for Psychological Experiments). Each participant was presented with 32 auditory warnings over headphones. Participants rated each stimuli on eight dimensions considered important in previous auditory warnings literature: discernibility, meaning, urgency, natural response, annoyance, startle, and overall appropriateness [6]. All warnings were controlled for volume and length (70 dB, 1-2 seconds). A collection of auditory icons (7), earcons (9), and verbal warnings (16) were generated for a total of 32 stimuli. Verbal warnings included the words “Caution”, “Alert”, “Warning”, and “Danger”, as either human (recorded voice) or synthetic (computer generated text-to-speech) in both male and female gendered voices (4 words x 2 types x 2 gender = 16 total verbal warnings). The seven auditory icons included a steam whistle, the sound of a train rolling across train tracks, standard active rail crossing warning bells, a steam whistle, a train horn, a combination horn plus tracks plus bells, a sound of change dropping into a cup was used as a training stimuli to ensure participants understood the instructions. These auditory icons were selected based on consulting with two rail research experts (one is professor and another is senior research engineer). Nine earcons were generated using the audio software, Audacity. Two were continuous pure tones (1000 or 2000 Hz frequency). Both tones were pulsed at either a faster or slower rate for an additional four stimuli. Two “siren” tones were generated oscillating between 1000 and 1500, or 1500 and 2000 Hz frequencies. The final earcon stimulus was generated to closely resemble the familiar airplane intercom ding. Stimuli were presented in the random order and participants had the option of providing short explanations for their ratings for each stimulus. Before the auditory warning survey was presented, each participant spent five minutes in a low-fidelity simulator to prime them for answering questions related to in-vehicle sounds.

3. RESULTS

Thirty-one (*Mean* age = 20.1, *SD* age= 1.7; 17 male, 14 female) psychology undergraduate participants completed the study in exchange for course credit. Descriptive statistics of the results of the survey were analyzed using R Studio/JASP. To determine the most preferred stimuli, mean “overall” ratings were plotted against the corresponding standard deviations (Figure 1).

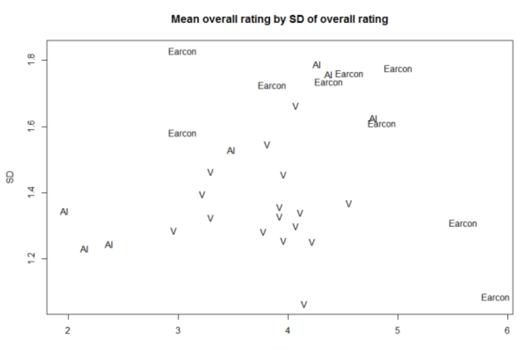

Figure 1: Mean overall rating against standard deviation of overall rating for each of the 32 stimuli (presented as warning “type”; V = verbal, Earcon, or AI = Auditory Icon).

Based on this metric, the two highest performing (with the most agreement) stimuli are the low siren and high-pitched faster beeps earcon. Contrary to the authors’ hypothesis, the majority of auditory icons (featuring various actual train sounds) were either consistently rated as not appropriate (mean < 2, low SD), or inconsistently rated as averagely appropriate (mean between 3-5, high SD). An interesting pattern emerged from the ratings for verbal stimuli, as the majority (all but one) is clustered in the center of the plot. Comparing overall ratings by type (figure 2) shows that due to the high variance within type groups, no statistically significant difference in mean ratings can be found. A repeated measures analysis of variance was conducted on the verbal warnings to investigate the effect of word, gender, and voice type on overall rating. Results indicate a significant effect for Gender, and Voice type, and interactions for Word X Gender, Word X Voice type, and 3 way interaction for Word X Gender X Voice type.

Repeated Measures ANOVA

	Sum of Squares	df	Mean Square	F	p
Between Subjects					
Residual	335.375	26	12.899		
Within Subjects					
Word	4.370	3	1.457	1.139	0.339
Residual	99.755	78	1.279		
Gender	9.481	1	9.481	9.252	0.005
Residual	26.644	26	1.025		
Voice	17.926	1	17.926	13.529	0.001
Residual	34.449	26	1.325		
Word:Gender	13.111	3	4.370	4.195	0.008
Residual	81.264	78	1.042		
Word:Voice	10.444	3	3.481	3.736	0.014
Residual	72.681	78	0.932		
Gender:Voice	3.000	1	3.000	1.874	0.183
Residual	41.625	26	1.601		
Word:Gender:Voice	15.296	3	5.099	5.061	0.003
Residual	78.579	78	1.007		

Note. Type III Sum of Squares

Figure 2: Repeated Measures ANOVA of “Overall” ranking by word, gender, and voice type.

4. DISCUSSION

Further analyses of subjective ratings of the auditory stimuli are ongoing. Urgency of word shows a similar pattern to Human Factors guidelines (e.g., Caution- Alert-Warning-Danger). However, given the three way interaction, there are more effects that can fade this main effect. In subjective surveys such as this, qualitative data can be as insightful as the quantitative. Based on the descriptions given by the participants, human voice recordings are preferred over synthetic voices due to the ability to convey emotional intensity of the voice actors. Many participants reported distaste for both verbal and auditory icons, and much preferred the presented earcons. Due to their nature, earcons have the advantage of audibility in noisy environments; however, they suffer from the non-obvious representation of their referents. It is possible that since all stimuli were meant to signal one event (an approaching train at an RR crossing); participants placed little importance on signal-to-referent transparency, biasing results in favor of earcons and against the train-related auditory icons. The results of this analysis will help the research team determine the most preferred auditory warnings to use in a follow up driving simulator study investigating driver behavior at rail road crossings.

5. REFERENCES

[1] https://safetydata.fra.dot.gov/OfficeofSafety/default.aspx

[2] M. Yeh and J. Multer, “*Driver behavior at highway-railroad grade crossings: A literature review from 1990-2006,”* Final Report, Federal Railroad Administration, Office of Research and Development, Washington, D.C., October 2008.

[3] http://www.angelsontrack.org/cts/ctsfacts.html

[4] C. L. Baldwin and B.A. Lewis, “Perceived urgency mapping across modalities within a driving context,” *Applied Ergonomics*, vol. 45, pp. 1270-1277, 2014.

[5] G. Peryer, J. Noyes, and K. Pell-Dell-Pearce, “Auditory alert characteristics: A survey of pilot views,” *International Journal of Aviation Psychology*, vol. 15, no. 3, pp. 233-250, 2005.

[6] A. K. Tan, and N.D. Lerner, “Multiple attribute evaluation of auditory warning signals for in-vehicle crash avoidance warning systems,” Technical Report, DOT HS 808 525, Washington, D.C., 1995.

[7] J. Belz, G. Winters, Robinson, and J. Casali, “A methodology for selecting auditory icons for use in commercial motor vehicles,” in *Proceedings of the Human Factors and Ergonomics Society*, 1997.